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NUMERICAL AND EXPERIMENTAL STUDY OF SANDWICH PLATES WITH METALLIC FOAM CORES

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Abstract. World-wide vehicles safety experts agree that significant further reductions in fatalities and injuries can be achieved as a result of the use of new energy absorbing materials. In this field, passive safety systems still have great potential to reduce fatalities and injuries, as in the case of using new lightweight energy-absorbing materials. On this work, the authors present the development of a procedure able to perform reliable panels of sandwich sheets with metallic foam cores for industrial applications. The mathematical model used to describe the behavior of sandwich shells with metal cores form is presented and some numerical examples are included. The numerical results are validated using the experimental results obtained from the mechanical experiments. Using the crushable foam constitutive model, available on ABAQUS, a set of different mechanical tests were simulated.

1 INTRODUCTION

Despite significant improvements in car safety in the last 25 years, the actual number of deaths and wounded arising from automobile accidents, in addition to all social and economic costs, remains unacceptable. Here, the passive safety systems still have great potential for development as a way to reduce deaths and injuries. On the other hand, from an environmental point of view, the use of materials optimized in terms of energy absorption, with a reduced weight, has a direct impact on the thermal efficiency, and consumption of the engines, thus emitting less greenhouse gases for the atmosphere. Within this framework, it makes sense the study and development of this new composite material, formed by two sheets of aluminium separated by a foam core of aluminium [1-2].

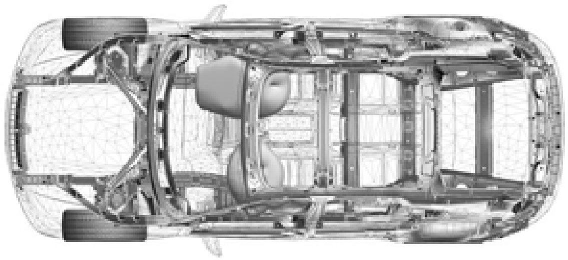


Figure 1: Example the study of passive safety systems [3].

The composite structure used on this work is formed by two sheets of aluminium with 1mm thickness, separated by a aluminium foam core with a thickness of 8mm. Since the specific characteristics of this composite material are mainly due to the behaviour of its core, namely the energy absorbing during impact and vibration isolation properties [4-5], the foam will be studied in detail on this work.

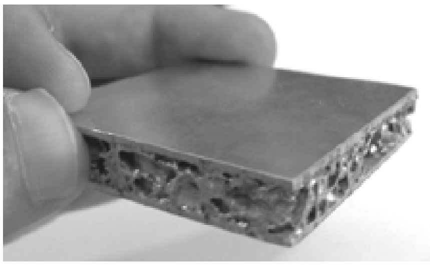


Figure 2: Panels with aluminum foam core.

The structure of the foam corresponds to a three-dimensional arrangement of cells, which can be divided into two groups: open and closed cells. On metal foam with open cells, the individual pores are open. When the individual pores are closed, the metal foam belongs to the closed cells group [6-7].

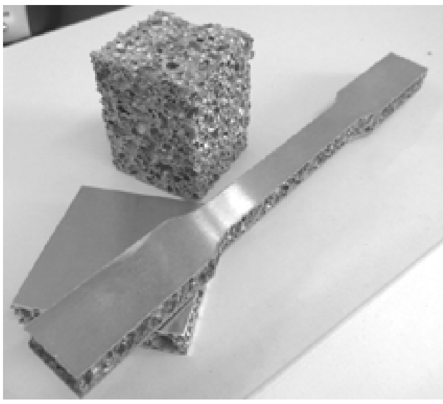


Figure 3: Specimens with aluminum foam core and metal foam.

2 CONSTITUTIVE MODEL

To describe the plastic behavior of the metal foam in this work, the constitutive model proposed by Deshpande was used [8]. This model was chosen due to its capability to describe the behavior of porous metals and due to fact that the yield surface used on this model depends only on the plastic Poisson's ratio.

2.1 Yield Surface

Metal foams have an approximately linear elastic behavior for small strains. Metallic foams plastic deformation occurs when there is a change in volume, unlike solid metals. For metal foams the yield criterion can be formulated as follows:

$$\hat{\sigma} \geq \sigma_y \text{ with} \tag{1}$$

$$\hat{\sigma}^2 = \frac{1}{(1+(\alpha/3)^2)}[(\sigma_e{}^2 + \alpha^2\sigma_m{}^2] \tag{2}$$

$$\sigma_m = -\frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) \tag{3}$$

$$\sigma_e \equiv \sqrt{\frac{3}{2}\sigma_{ij}{}' : \sigma_{ij}{}'} \tag{4}$$

Where the equivalent stress is given by $\hat{\sigma}$, and σ_e is the von Mises equivalent stress. σ_m is the mean stress and is defined as $\sigma_m = \frac{1}{3}\sigma_{kk}$. The shape of the yield surface is defined by α and σ_y is the yield stress of the material [1].

Considering the stress plane σ_m, versus stress equivalent σ_e, from Figure 2 is possible to obtain the points 1, 3, 6, 8 that define the yield surface. These points were obtained by varying the pressure *p*, and the uniaxial load [8-9].

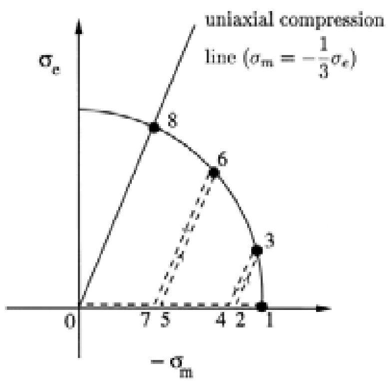


Figure 4: Definition of the yield surface Deshpande model.

2.1 Deshpande Model

Based on the experimental results of the definition of the yield surface previously presented, but now considering a reference $\sigma_m \rightarrow p$, $\sigma_e \rightarrow q$, the model of Deshpande [10] can be summarized as follows:

Elastic law:

$$\boldsymbol{\sigma} = \mathbf{D}^e : \boldsymbol{\varepsilon}^e$$

Yield Surface:

$$\phi = \sqrt{\frac{1}{1+\left(\frac{\alpha}{3}\right)^2}\left[q^2 + \alpha^2 p^2\right]} - \sigma_y(\bar{\varepsilon}^p) = 0$$

Plastic evolution law:

$$\dot{\boldsymbol{\varepsilon}}^p = \dot{\gamma}\boldsymbol{N}$$

Elastic evolution law:

$$\dot{\varepsilon}^e = \dot{\varepsilon} - \dot{\gamma}\boldsymbol{N}$$

Evolution of the equivalent plastic strain:

$$\dot{\bar{\varepsilon}}^p = \dot{\gamma}\sqrt{\frac{2}{3}\boldsymbol{N} : \boldsymbol{N}}$$

3 EXPERIMENTAL TESTS

To validate the numerical model previously presented, uniaxial compression tests of samples obtained from the panels were performed. Figure 5 illustrates the experimental procedure, from which it was possible to record force/displacement values for this material, which are then compared with the numerical values. This mechanical test is one of the tests commonly used to characterize the mechanical behavior of metallic foams.

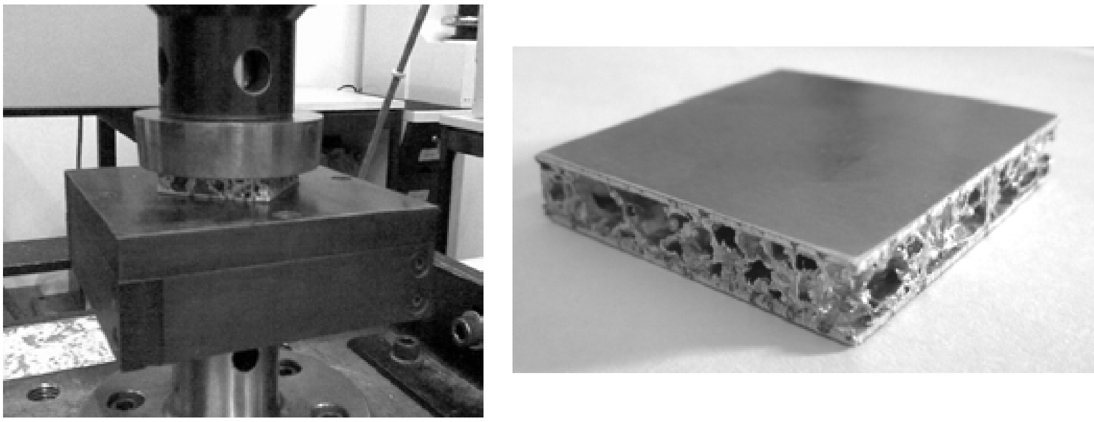
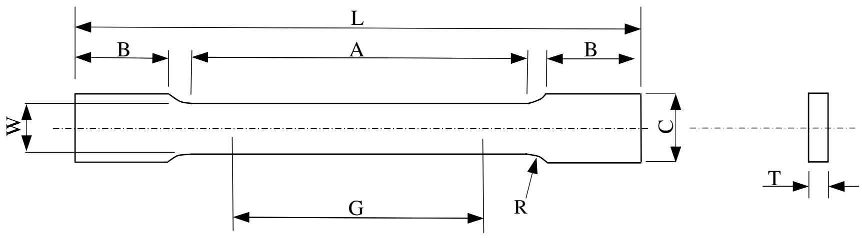


Figure 5: Uniaxial compression test.

Tensile tests were also performed in order to evaluate the mechanical behavior of this composite material under traction. To this end specimens were cut from the panel with the dimension shown on Figure 6.



G=50 mm,
W=12.5 mm,
R=20 mm,
L=200 mm,
A=75 mm,
B=50 mm,
C≈20 mm,
T- Thickness [mm]

Figure 6: Specimens used on the tensile test, according to ASTM E 8M-04.

The following Figure shows de experimental setup used to conduct the tensile tests.

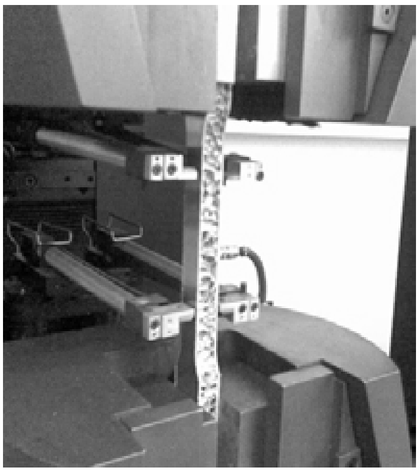


Figure 7: Experimental tensile test.

4 NUMERICAL SIMULATIONS

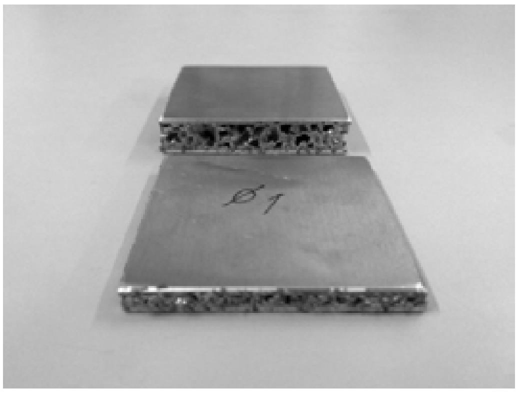
Numerical simulations of the same experimental tests were performed. For the aluminum sheet an elasto-plastic behavior was assumed with Young module: 70 GPa, Poisson ratio: 0.33 and points from the yield stress/plastic strain curve. For the metallic foam core an elasto-plastic behavior was also assumed, based on the model previously defined. The properties used to describe the metal foam behavior are the Young module: 0.354 GPa, Poisson ratio: 0.33, Compression Yield Stress Ratio: 1.71, plastic Poisson ratio: 0.013 and points from the yield stress/plastic strain curve. The stress-strain curve obtained by the uniaxial compression test is also used to describe the metallic foam behavior [8, 11-12].

The numerical simulations were conduct using the software ABAQUS. Only 1/8 of each specimen was represented numerically in order to minimize the computational effort, and improve the quality of the approximation given by the finite element method.

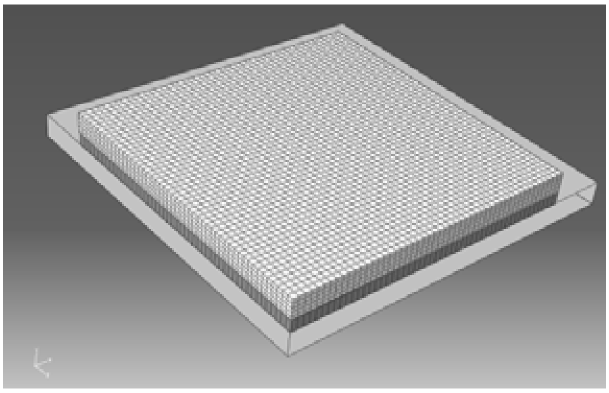
5 PRESENTATION AND DISCUSSION OF RESULTS

Figure 8a shows the spciments before and after the compression test. It can be observed the high volume change by compression, suffered by the foam.

Figure 8b shows the deformed mesh obtained for the numerical simulation of the compression test.



a) Final result of experimental compression test.



b) Final numerical result.

Figure 8: Compression test.

Comparison of the results in terms of force-displacements graph shows a good agreement between the numerical results obtained using the Deshpande model and experimental results.

For the numerical test, the metal foam core assumes an important role. After a small domain of elastic behavior, the foam quickly reaches its yield value. This can be physically interpreted as the beginning of the collapse of the cells that constitute the foam. This process is almost constant with some small variations in strength. After all the cells have collapsed, the numerical specimen starts behaving as a solid, resulting on a rapid increase on the applied force for small increments of displacements.

A good agreement was obtained between the numerical results and the experimental results. This validates the use of the Deshpande constitutive model, used to describe the difficult behavior of plastic porous materials.

Figure 9 shows the speciments after the tensile tests experiments. The obtained numerical and experimental results for the tensile tests are shown in Figure 10. Observing the force/displacement curves of Figure 10, they appear to be similar to a typical curve of a tensile test for an homogeneous solid metal, with an initial elastic behaviour and a second plastic behaviour. The high forces that leads to the rupture of the speciments are mainlly supported by the two aluminum sheets, since the rupture of the metal foam core occurs for much lower forces than those achieved during the experimental tensile tests.

Figure 9: Specimens after the tensile test.

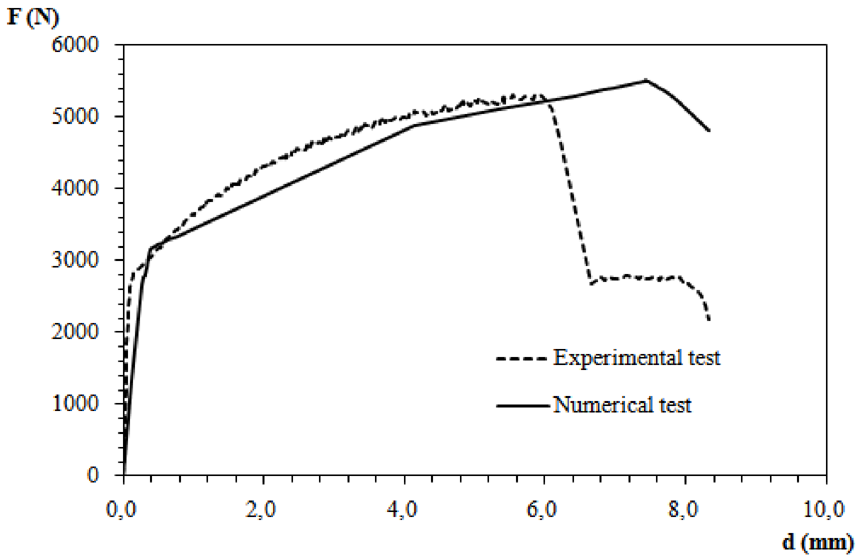


Figure 10: Force/displacement curve for the experimental and numerical tensile test.

6 CONCULUSIONS

A good agreement was verified between the numerical and experimental results for the uniaxial compression test. It is possible to conclude that the model of Deshpande can be used to describe the plastic behavior associated with the metal foam cores.

For the tensile test a good agreement between the numerical and experimental results was obtained. It is also still possible to conclude that the aluminum sheets are the main responsible for the high force achieved experimentally, due to the foam’s low ability to withstand tensile forces.

Finally, and as a way to improve the numerical results, additional experimental studies would be needed in order to obtain the properties of the sheets separated from the foam, and an approach to study the anisotropy associated with both materials that constitute these panels.

ACKNOWLEDGEMENT

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